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Five tasks were initiated to study the aerodynamic interference between stores and aircraft. Both visous and inviscid calculations were made. Steady state interference calculations matched well with experimental results and with other computational results. Unsteady time-accurate inviscid results showed the feasibility of using the Chimera scheme to simulate store separation. Free-fall calculations were made, demonstrating the ability to compute the new position of the sore from the aerodynamic forces and moments on the store after its release from the aircraft.

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Aerodynamic Interference Between Stores

Air Force Office of Scientific Research
Award Number: AFOSR-89-0235

Final Report for the Period
February 1, 1989 - June 30, 1991

Submitted by F. Carroll Dougherty, Principal Investigator
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Aerodynamic Interference Between Stores

Final Summary

Objectives: To study the aerodynamic interference between stores as a function of the separation distance. To analyze the viscous interaction between stores and its effect on the forces and moments on the stores. To simulate time-accurate store separation trajectories, both prescribed and free fall.

Approach: Coupling existing implicit, ADI computational codes with the multiple mesh Chimera scheme to evaluate the interference between closely coupled bodies.

Progress: Five studies were made during the course of this contract. Three, the generation of a wing-pylon-store configuration, time-accurate transfer of boundary information across Chimera interfaces, and viscous interaction between stores, were discussed in the anual report last year. An offshoot task from the wing-pylon-store configuration that allowed for more accurate block-to-block boundary conditions, and the time-accurate simulation of free-fall store release were continued into the second year. Each of these efforts will be briefly discussed below, and a summary of publications will follow.

Wing-Pylon-Store: A series of grids were generated for the wing-pylon-store with sting configuration that Eglin AFB has been using for its test cases. The grids are designed for an inviscid calculation, and a total of 8 grids were used (figure 1). Two grids were generated about the wing, with the inside grid generated about the wing surface, and the outside grid forming a shell around the entire configuration. Two smaller grids were generated about the pylon; one along the bottom surface and one about the pylon surface. The upper surface of the pylon grid was flush with the wing surface. The store with fins and a sting was modelled with 4 meshes, with the store divided into quarters along the centerlines of the fins. The EAGLE grid generation code was used to generate these grids.

An interesting problem came up with these grids before they were tested with the flow solver. The block-to-block boundary conditions at the interfaces along the fins on the store grids and on the pylon lower surface were not being computed properly by other parties using blocked grids with the Chimera scheme. The existing interpolation procedures did not allow for the flow to proceed from block to block in a natural fashion, but constrained it with unphysical restrictions. The members of the computational group at Eglin asked us to investigate a better method for interpolating at these boundary interfaces. We initiated a study to use the capabilities of the Chimera scheme to overcome the difficulties at the block boundaries for the second year of this contract.

Time-Accurate Boundaries: A study was performed to evaluate the time-lag error across the interface boundaries for moving Chimera grids. We attempted to isolate the error and tried to correct it. It was determined that this error was quite small once the one-sided differencing of the metrics was eliminated. The error due to the difference in cell volume and orientation between grids was still the dominant error for the transfer of information across the chimera interface boundaries.

Several methods to correct the grid errors were tried, and a couple were found to make a small difference. A paper on the preliminary results was presented at the AIAA 9th Computational Fluid Dynamics Conference in Buffalo in 1989, and the final results were published as a Ph.D. thesis through the University of Colorado, which is listed in the bibliography. The removal of the one-sided differencing and a relaxation technique were the most promising of the correction techniques, and both have been implemented into the HYDRA code. The relaxation technique was applied to the store separation simulation of an elliptic store under the Eglin Delta wing, where the relaxed calculation yielded the same result for a larger time step using 28% less CPU time than the unrelaxed case (figure 2). In figure 3, the pressure coefficients for the relaxed and unrelaxed cases at the two different time steps are shown to be the same, and the pressure coefficients for the two cases with the same, larger time step shows that the unrelaxed case is unstable at the larger step.

Viscous Interactions: The primary effort for this contract has been the study of the viscous interactions between stores in close proximity. The intent was to compare our results with experimental data determined by Eglin AFB and with a set of alternate finite-volume calculations computed at Eglin. The implicit ADI flow solver, F3D, was coupled with the Chimera scheme to model a two store configuration. Symmetry conditions were used so that only one store and a reflection plane are modelled. The Eglin finite-volume computations were computed on a blocked grid generated by the EAGLE grid code and simulated with the EAGLE flow solver. The blocked grid had a singularity in the field ahead of the store, and the position of the store with respect to the reflection plane could not be easily changed. Their results agreed well with the experimental data.

The mutual interference configuration consisted of two axisymmetric stores separated by a small distance. The store geometry had a tangent-ogive forebody, cylindrical centerbody, and a tangent-ogive afterbody as shown in figure 4. The stores had a nondimensional chord length of 1 and a separation distance from body centerlines of 1.8 body diameters. The configuration was mapped using three grids coupled by the Chimera scheme. Only one store was

actually used in the computation, and the effect of the other store was felt using a reflection plane boundary condition located halfway between the stores (i.e. .9 body diameters from the store centerline). A single body-conforming grid was generated about the store using a hyperbolic grid generator. The reflection plane was modeled with two Cartesian grids. A fine inner Cartesian grid communicated with both the store grid and the coarse outer Cartesian grid. The outer grid mapped the domain to the far field. The overall grid dimensions were -3.0 to 4.0 in x, -6.0 to 6.0 in y, and 0.0 to 6.0 in z. Steady state results were computed for freestream Mach numbers of .95 and 1.05. We were unable to commence unsteady calculations because of computer communication problems.

The steady state results for the two-store interference at freestream Mach number 1.05 are shown in figure 5. The pressure coefficients along the inboard and outboard positions are plotted and compared with experiment. Good agreement is shown for both positions, and excellent agreement is also shown when compared with the results of Lynch and Rizk of Eglin AFB, although that is not shown here due to incompatibility of data formats. Pressure coefficients for both positions for the Mach number .95 case are shown in figure 6, and agian shown good agreement with experiment. Further refinement of the grid at the fairing and the trailing edge showed a slight improvement at those positions.

Block-to-Block Boundary COnditions: Blocked or patched grids have been considered a subset to the Chimera grid scheme, but until now have not been used with overset grids to mesh complex configurations. When the wing-pylon-store configuration was under study, the need for good transfer of information across blocked boundaries came up. Since the blocked grids were embedded within other Chimera grids, the transference had to be consistent with the Chimera scheme. The block-to-block boundary conditions developed here use phantom points to transfer information across block interfaces using the bookkeeping developed for the Chimera scheme. For the present, block boundaries occur only at constant k-planes, but extension to blocked grids along j or l-planes would be relatively straightforward.

With blocked grids we want to use flow data from points in the neighboring blocks for boundary conditions. This is illustrated in the following example. A four-block grid has been generated about an axisymmetric store. A cross-sectional view (constant j-plane) is shown in figure 7, where the solid lines represent block boundaries and the dashed lines are interior grid lines of a given block. From the figure, it can be seen that the k=1 plane of Block **I** is the same as the k=kmax plane of Block **IV**. Similarly, the k=kmax plane of Block **I** is equivalent to the k=1 plane of Block **II**. Therefore, the phantom points for Block **I** will come from Block **IV** for the $k_{\mathbf{I}}=1$ boundary and from Block **II** for the

k_I=kmax boundary (here the subscript denotes the block number).

In the computational domain, however, we want to enlarge the block to include the two planes on either side of each block. Looking at Block **I**, for example, we want to add the $kmax_{IV}$-2 and $kmax_{IV}$-1 planes from Block **IV**, as well as planes 2 and 3 from Block **II**. Therefore, in the new Block **I**, the $k_I'=1$ plane (here the prime denotes the new block to be used in the computations) will be equivalent to $k_{IV} = kmax_{IV}-2$ and $k_I'=2$ will be equivalent to $k_{IV} = kmax_{IV}-1$. Similarly, at the other boundary we have $k_I' = kmax_I'-1$ equivalent to $k_{II}=2$ and $k_I' = kmax_I'$ equivalent to $k_{II} = 3$. This new Block **I** is shown in figure 8 where the solid lines represent the block boundary, dashed lines are points interior to the block, and the dotted lines represent the phantom points that make up the k-plane boundary conditions. From this figure, one can see that the k=1 and k=kmax planes (the block boundaries) are computed as field points of the block. Since the fourth-order numerical dissipation in the η direction requires two planes of data to either side, two layers of phantom points are required to maintain central differencing. To avoid any one-sided differencing at the first and last k-planes in the physical grids, both layers of phantom points at each block boundary have their IBLANK values set to 0 and are updated by the flow variables within their home blocks.

Steady state viscous results for the blocked grids for the two-store case are shown in figure 9. Direct comparison with the two-store computations from the mutual interference study shows no difference between the two calculations, validating the block-to-block boundary conditions built into the flow solver. The figure compares C_p distribution along the inboard and outboard positions for the blocked grids, original grids, and experiment. Preliminary calculations for the store with fins case were promising, but were cut off when computer communications were shut off to the student preforming the work.

For the finned store, the need to account for the solid surface region within a block arises. With the Chimera scheme we can handle this porblem quite easily. Since both phantom planes have their IBLANK values set to 0, we can simply set IBLANK=0 on the solid surface and apply the tangency or no-slip boundary conditions as appropriate. Hence the solid surface will be introduced as a boundary condition in the flow solver. The differencing at the solid surface is one-sided. For the case of the finned store, there are exactly the right number of grid points in the neighboring blocks to create the phantom planes. However, there will be cases where this will not always be possible. This isn't a problem because these points will not be involved in the computation (the IBLANK values

are 0 and they are only used to transfer information), so they may be assigned an arbitrary value.

Store Separation SImulation: The final task for this contract involved the simulation of store separation from aircraft. The test case modeled an axisymmetric store (10% thick ellipsoid) of nondimensional chord length 1 under the AFATL delta wing used at Eglin AFB. The grids for these cases are shown in figure 10. Three Chimera grids were used: one about the store, a second about the wing, and a third about the whole configuration to the far field domain. The toal number of grid points was 637,275 points. The first studies, discussed in earlier reports, involved time-accurate inviscid simulation of the store following a predetermined path. The second phase initiated the free fall trajectory calculation effort for computing the paths of separating stores from the forces and moments on the store surface. The computed forces and moments were input to a six-degree-of-freedom subroutine that calculated the new position and orientation of the store for each time step. A preliminary calculation for an average 2000 lb store is shown in figure 11. The steady state initial condition is shown in the first of the two figures, and the free fall calculation after 200 iterations (approximately 2 msecs) is shown in the second. The simulation is slightly different from the predetermined trajectory (downward translation with a pitch-down rotation) simulation (figure 12) in the presented view, but the free fall simulation shows a yawing of the store that was not built into the predetermined trajectory.

Summary: Five tasks were initiated to study the aerodynamic interference between stores and aircraft. Both viscous and inviscid calculations were made. Steady state interference calculations matched well with experimental results and with other computational results. Unsteady time-accurate inviscid results showed the feasibility of using the Chimera scheme to simulate store separation. Free-fall calculations were made, demonstrating the ability to compute the new position of the store from the aerodynamic forces and moments on the store after its release from the aircraft.

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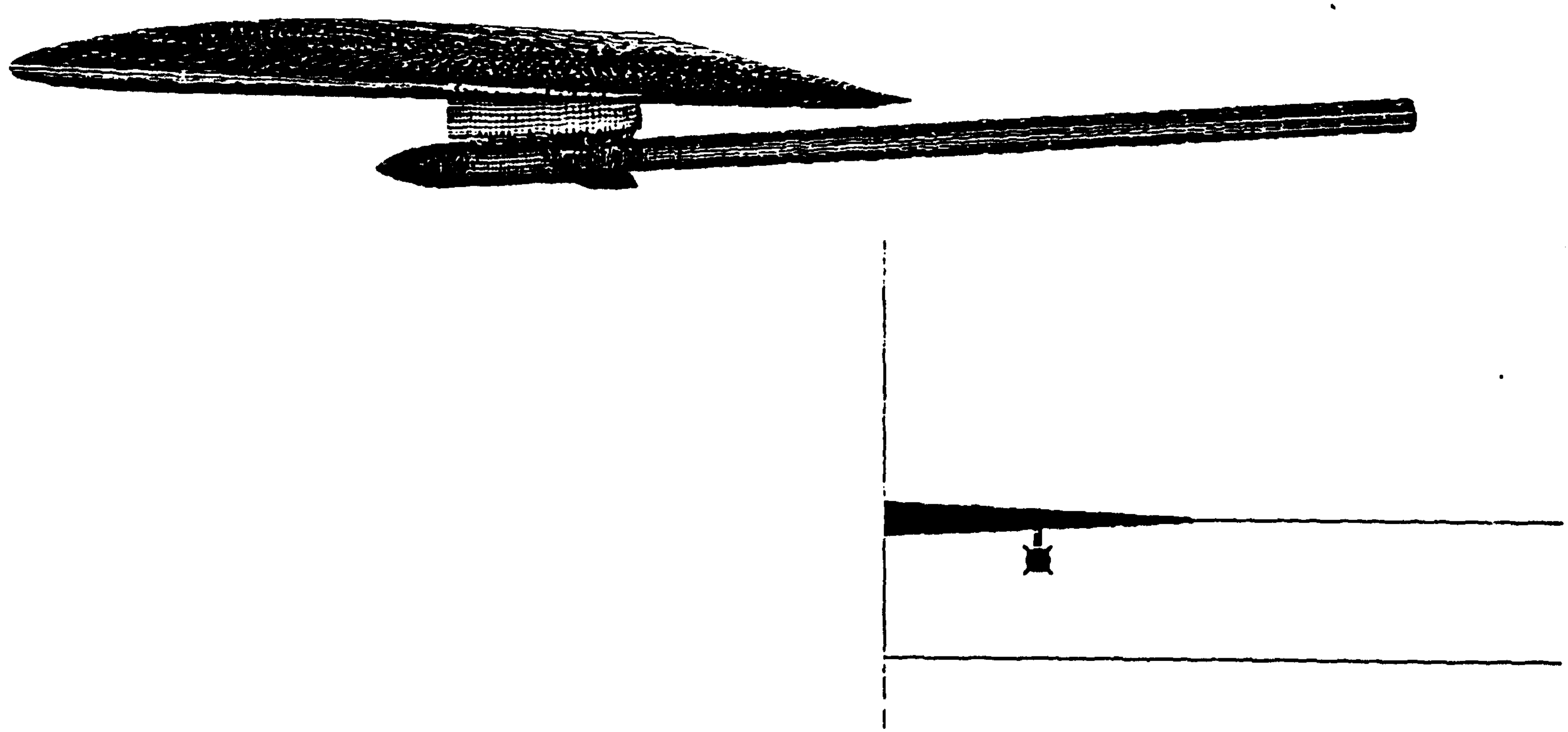

Figure 1.0 Wing-Pylon-Store surface grids.

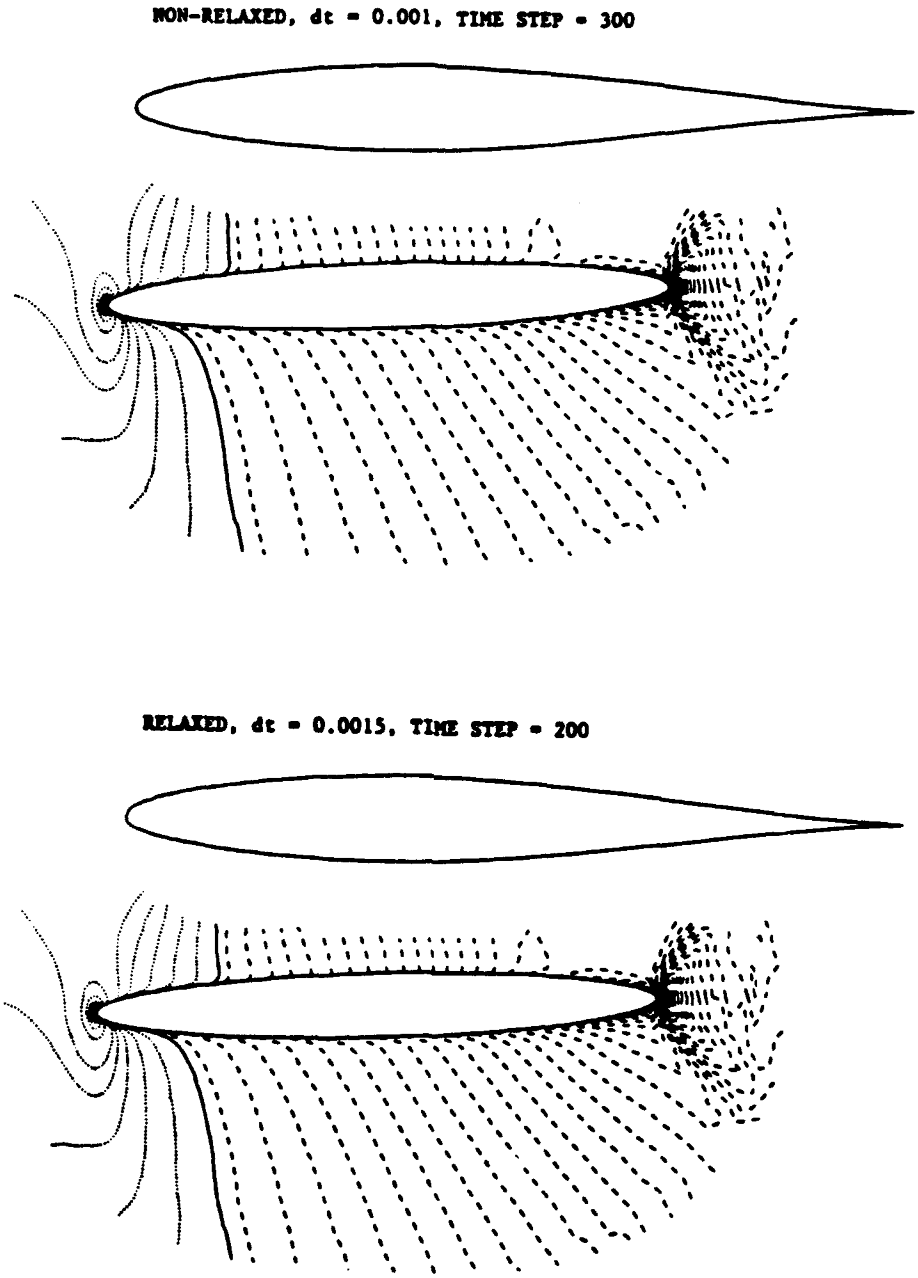

Figure 2 Mach contours for center planes of store for time=0.3 for relaxation and non-relaxation solutions.

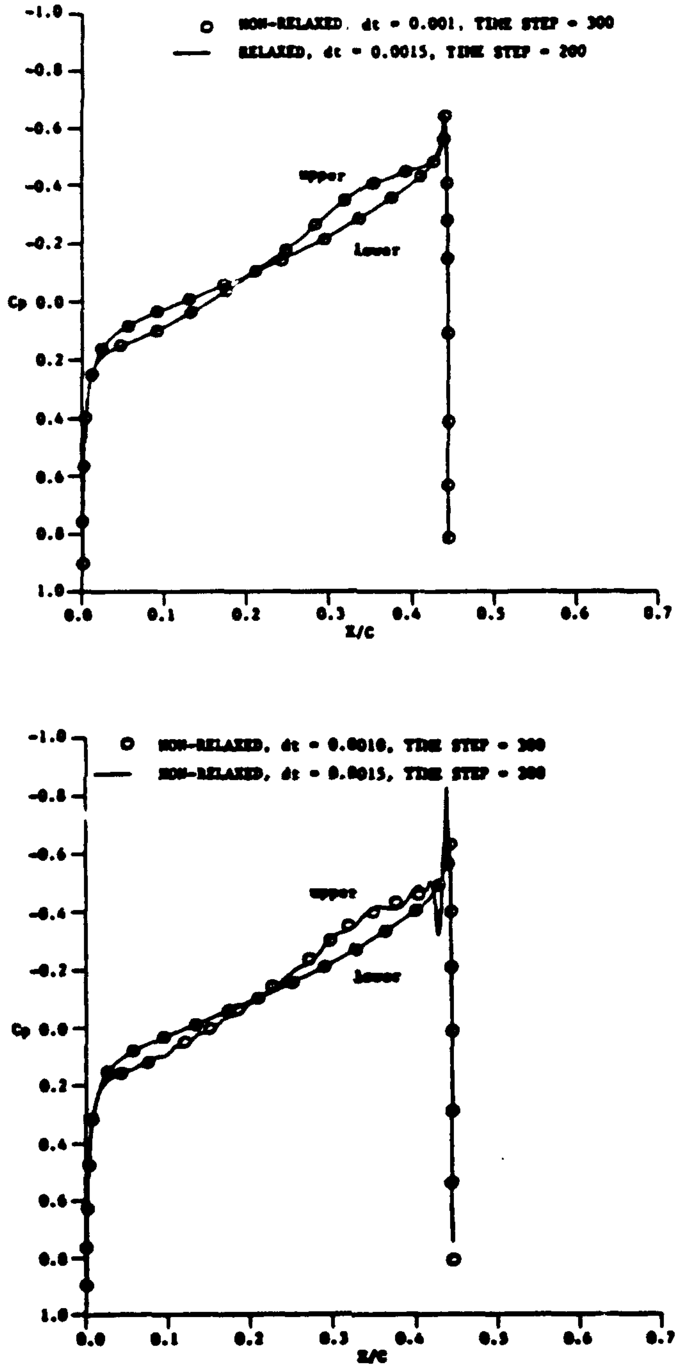

Figure 3 Pressure coefficients for center planes of store for time=0.3 for relaxation and non-relaxation solutions.

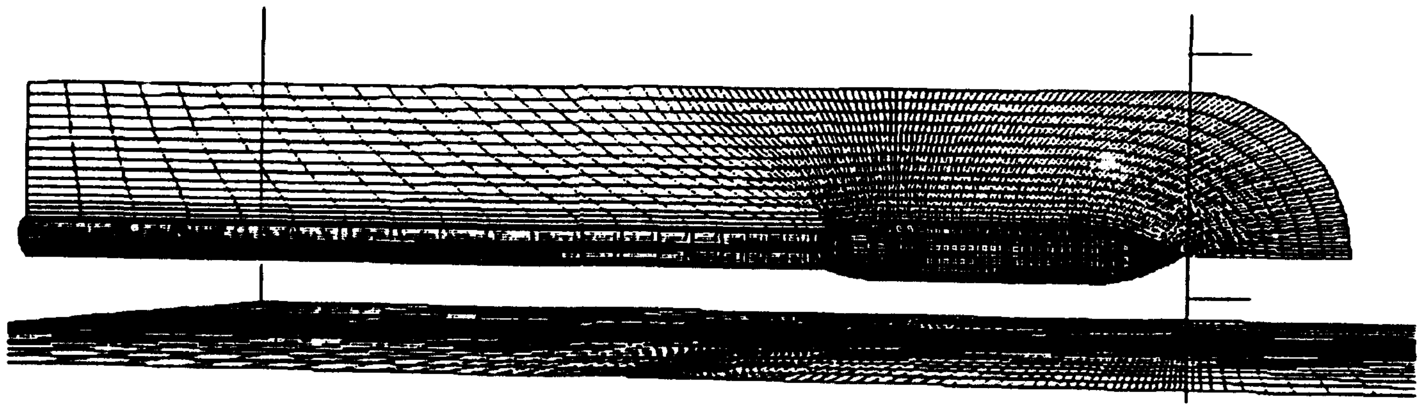

Fig. 4 Store and reflection plane for mutual interference case.

Cp DISTRIBUTION at FSMACH = 1.05

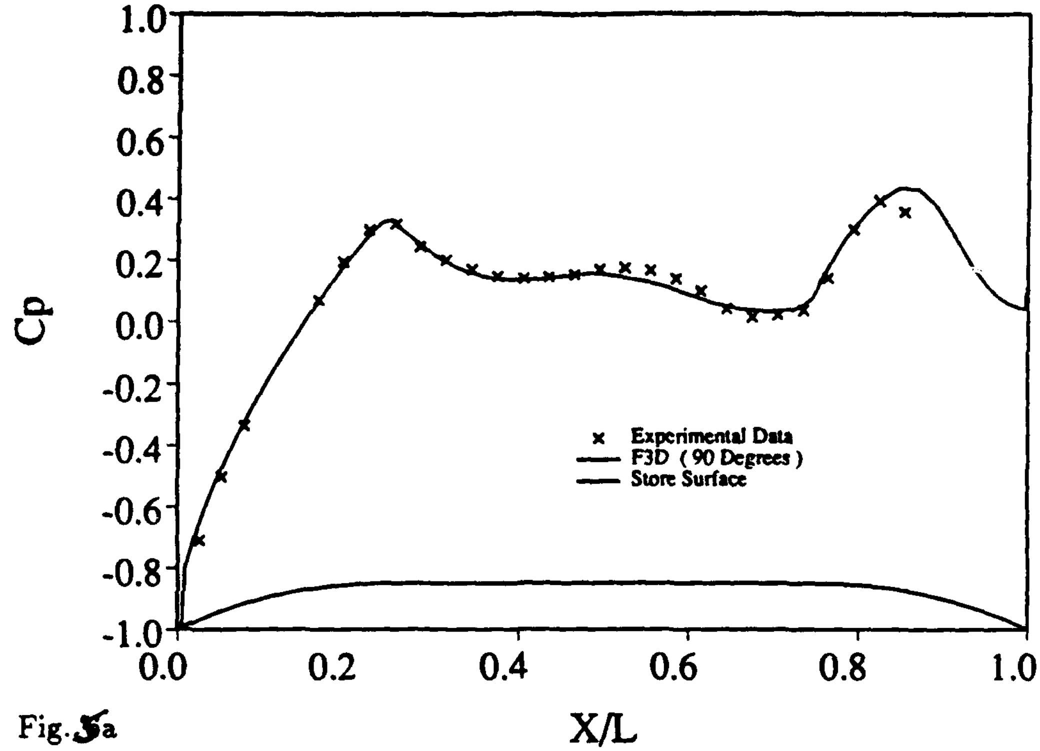

Fig. 5a

Cp DISTRIBUTION at FSMACH = 1.05

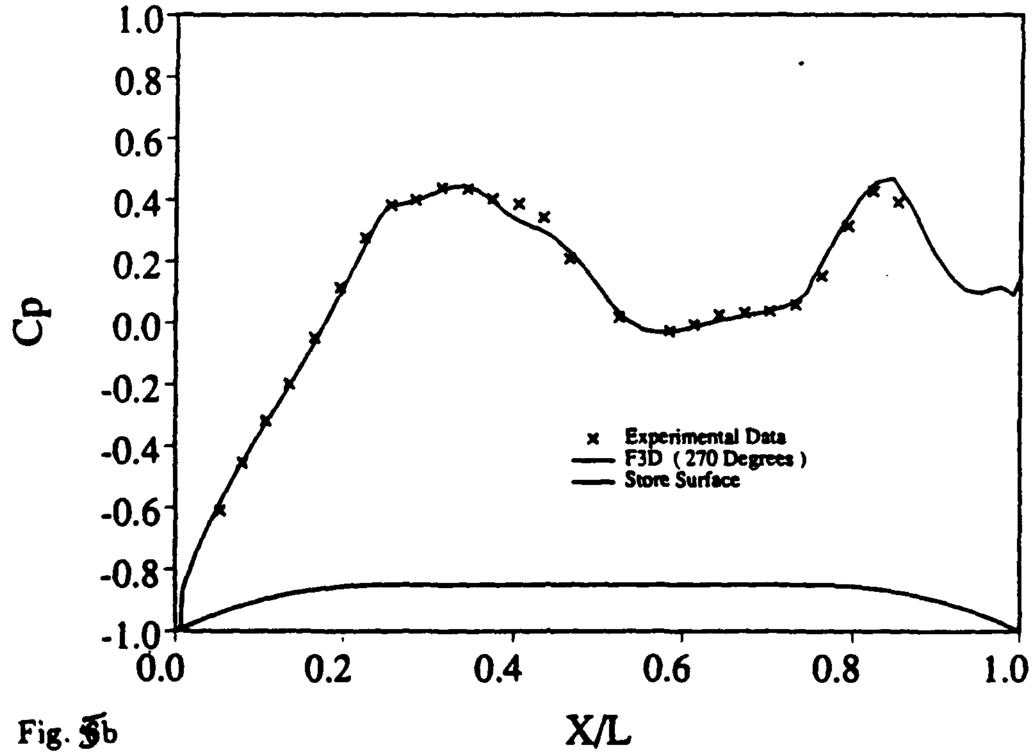

Fig. 5b

Cp DISTRIBUTION at FSMACH = 0.95

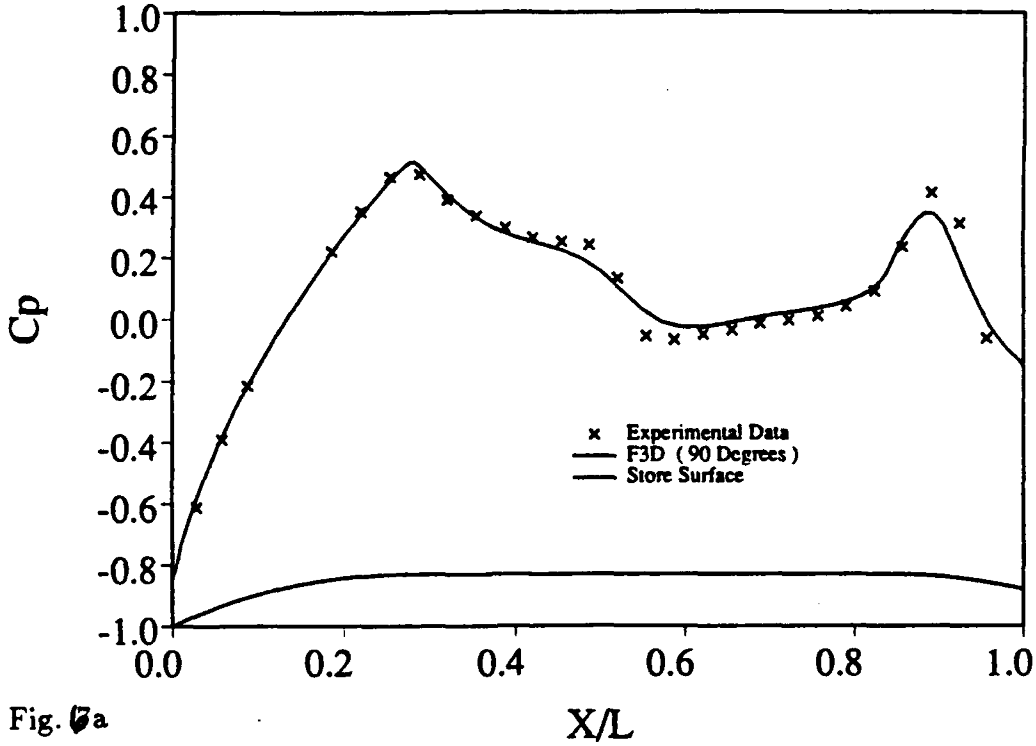

Fig. 6a

Cp DISTRIBUTION at FSMACH = 0.95

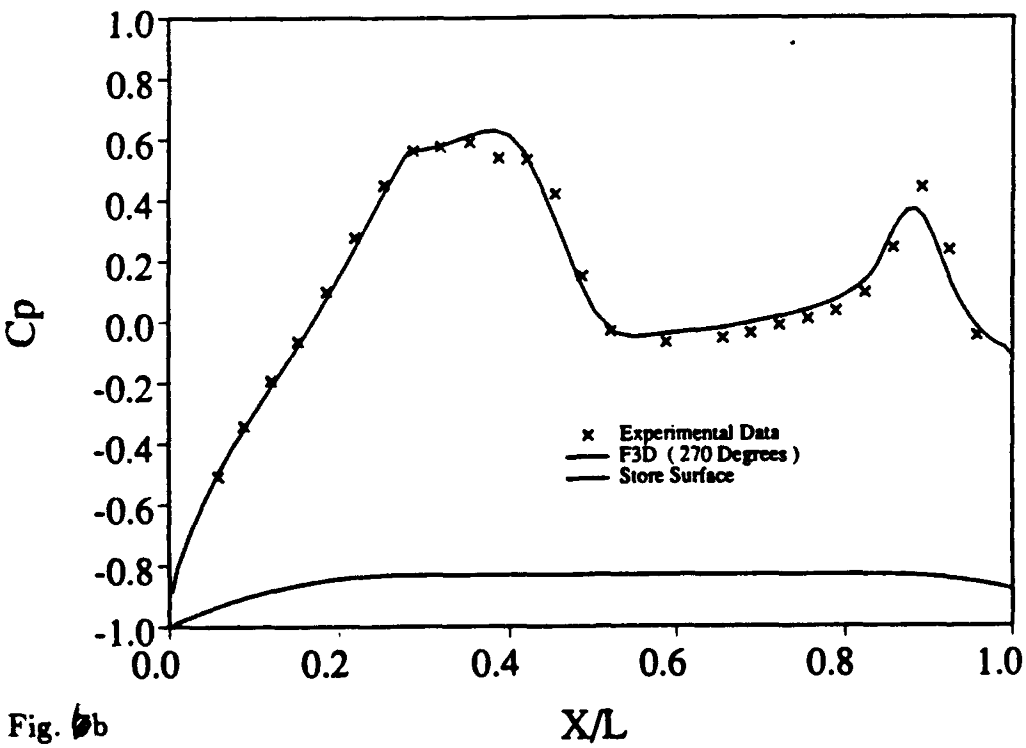

Fig. 6b

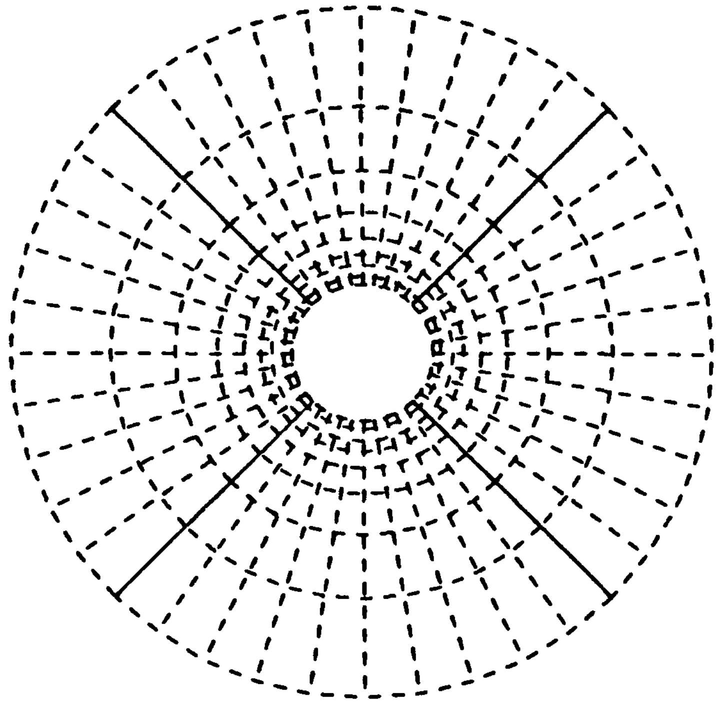

Fig. 7 Four block grid for axisymmetric store, physical domain.

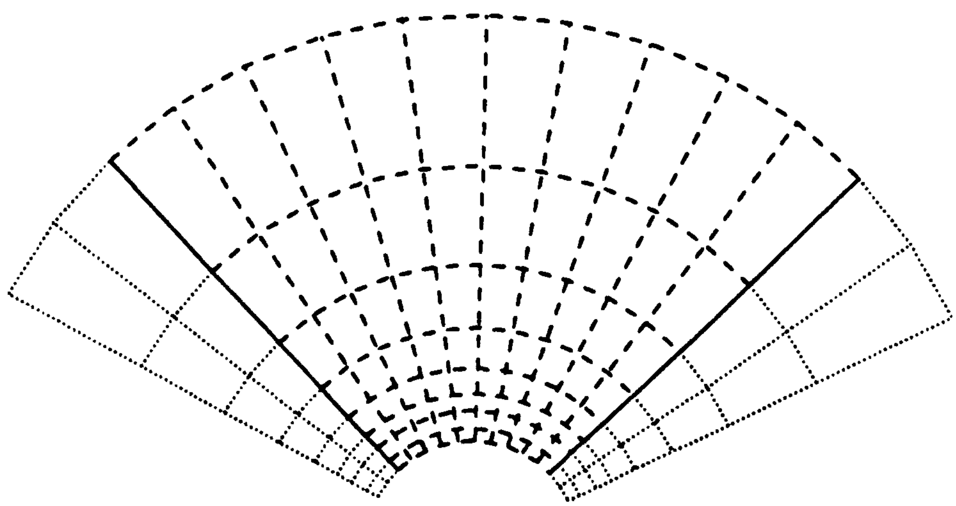

Fig. 8 Block I in the computational domain.

Cp DISTRIBUTION at FSMACH = 1.05

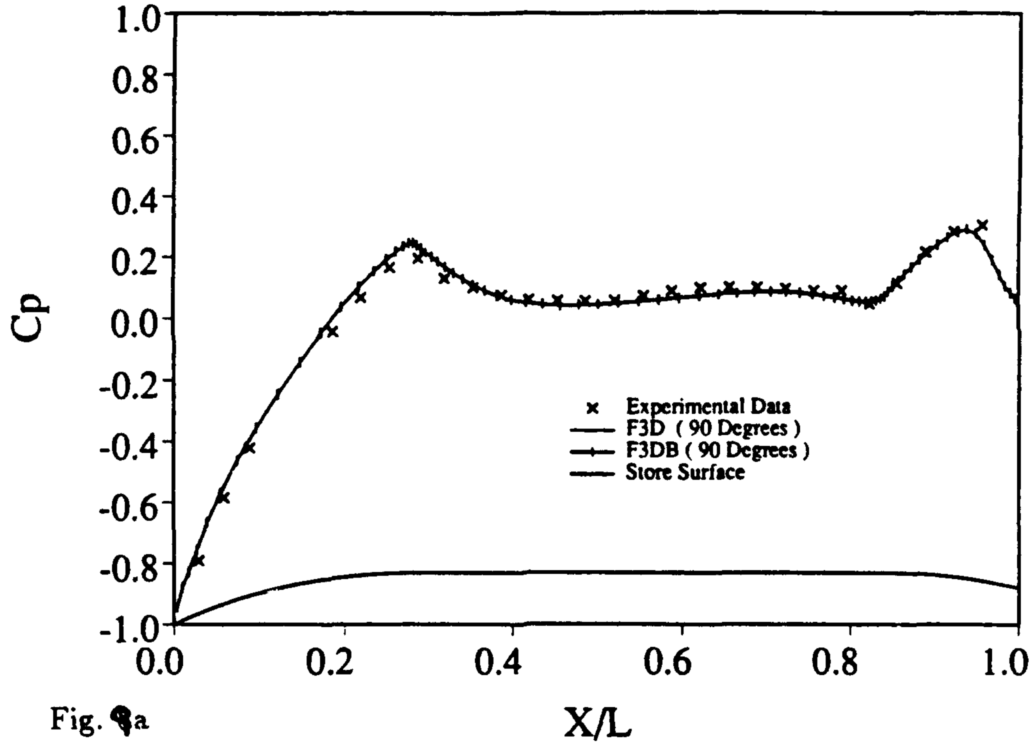

Fig. 9a

Cp DISTRIBUTION at FSMACH = 1.05

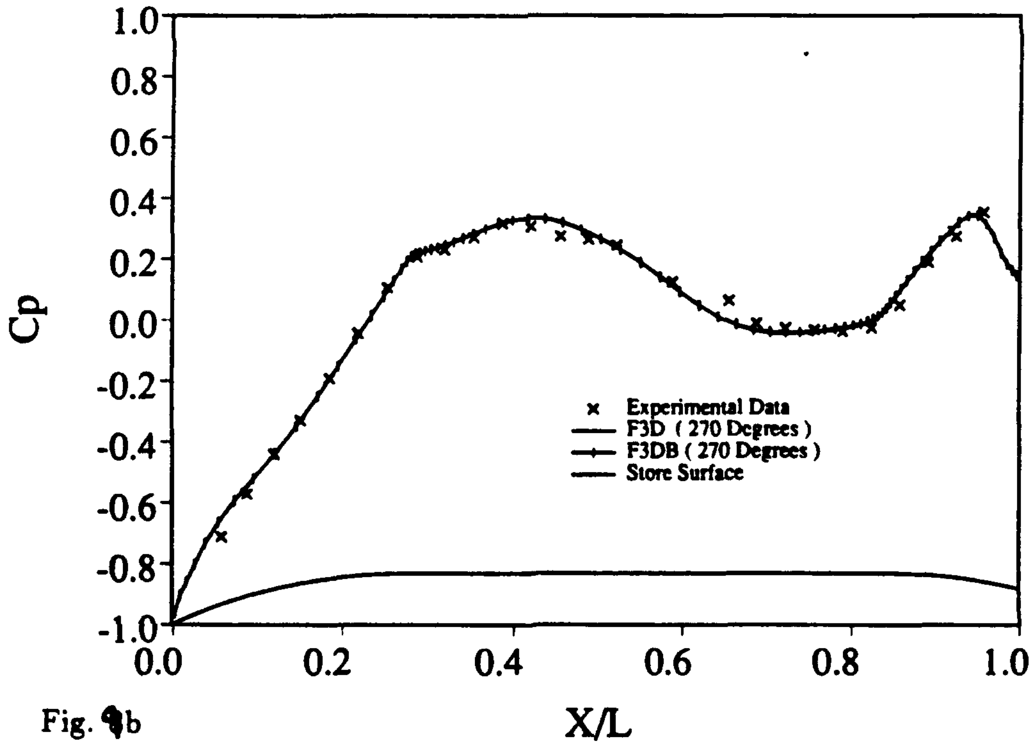

Fig. 9b

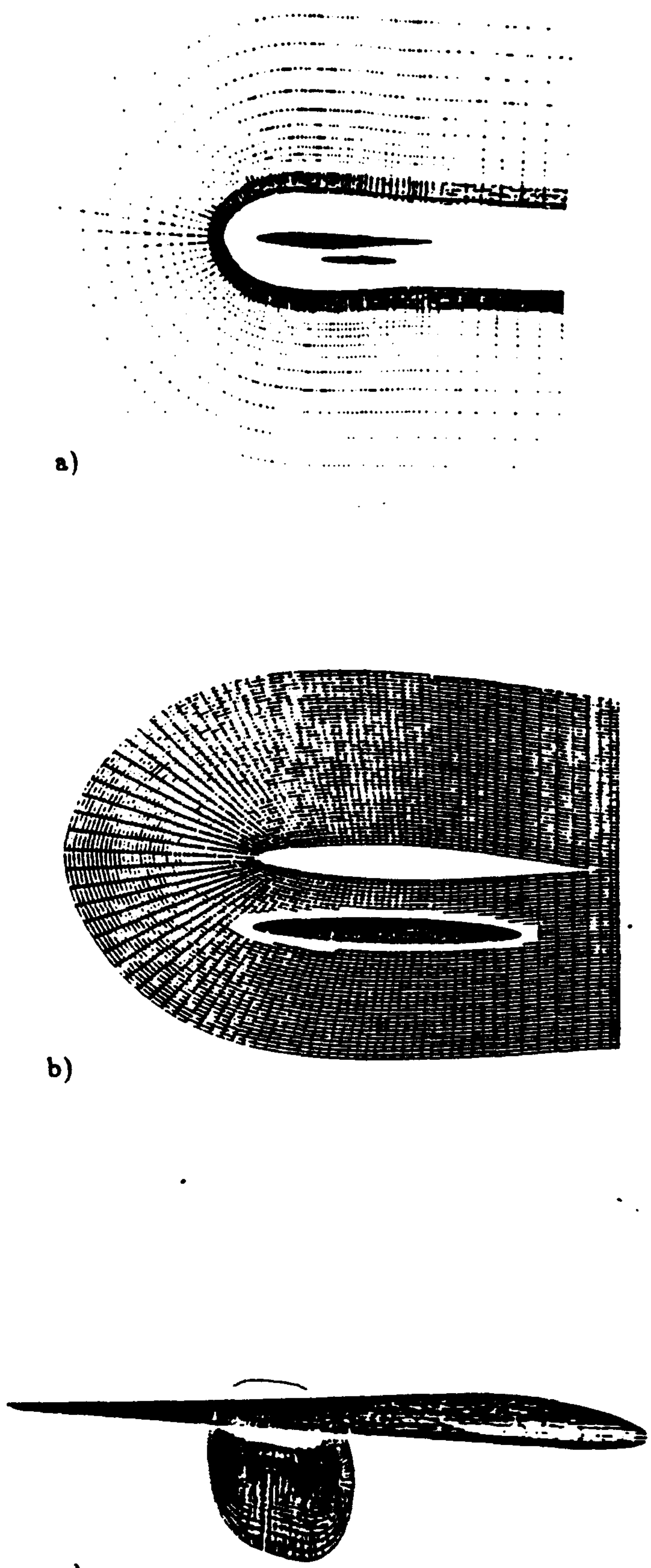

Fig. 10 Grids for store under AFATL wing.

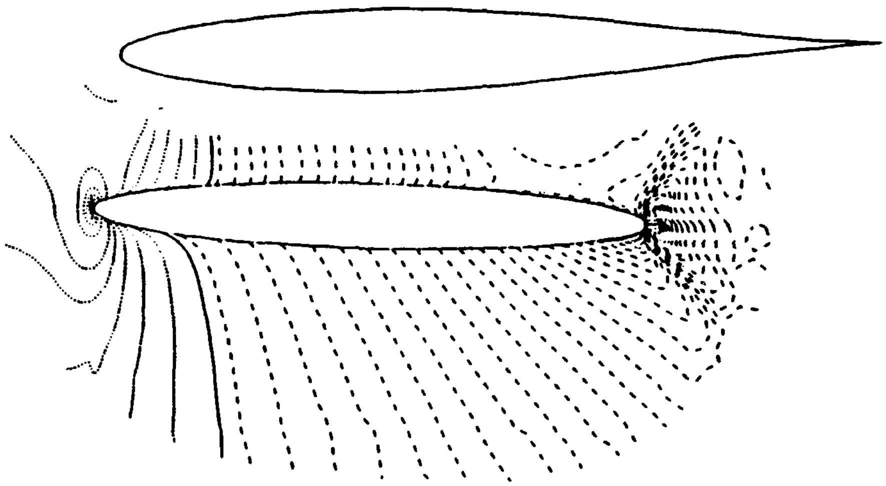

Fig. 10a Mach contours for steady state solution at center planes of store ($M_0 = 1.05$).

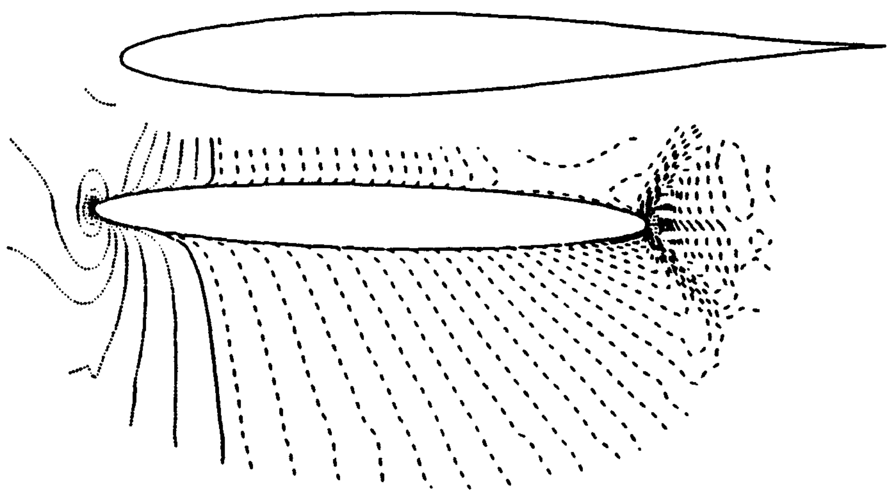

Fig. 10b Mach contours for free fall calculation after 200 time steps ($M_0 = 1.05$).

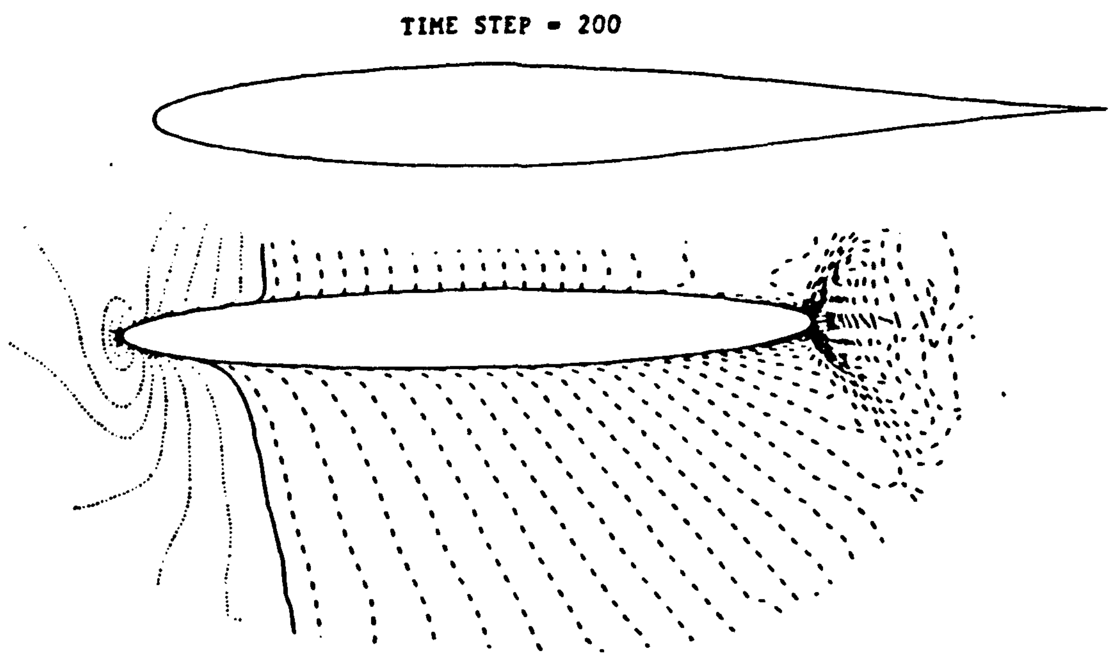

Figure 12 Mach contours for predetermined trajectory after 200 time steps (M_0=1.05).